Improves Air Quality:

- Because this practice can reduce energy usage, it can also reduce the amount of air pollutants being emitted from power plants.

Reduces Atmospheric CO_2:

- Water harvesting captures rainfall onsite, which can enable communities to reduce the amount of water treatment needed, in turn reducing CO_2 emissions from power plants.

Cultivates Public Education Opportunities:

- Managing future economic and environmental constraints will require full community participation and partnership. Green infrastructure provides an opportunity to develop community awareness and understanding around the importance of sustainable water resource management.
- By providing educational programs through fun activities such as rain barrel design and usage, communities can more effectively train residents in the benefits of green infrastructure.

Rainwater has been found to help improve plant health. Unlike potable water which contains salt, rainwater typically contains nutrients such as nitrogen and phosphorus, which is good for plants.

Economic Valuation in Action

Economic Valuation Methods & Tools

Comparing the benefits of different stormwater management practices requires a common unit of analysis. In making decisions about infrastructure investment, the value of a given set of possible investments is typically expressed monetarily.

One challenge inherent in valuing services provided by green infrastructure is that many of these services are not bought and sold. Fortunately, many techniques have been developed in order to economically value nonmarket ecosystem services. Nonmarket valuation methods include revealed preference methods, stated preference methods and avoided cost analysis.

Revealed preference methods attempt to infer the value of a nonmarket good or service using other market transactions. Hedonic pricing, for example, assumes that the price of a good is a function of relevant characteristics of that good and attempts to isolate the contribution of a given characteristic to the total price (most commonly used with housing prices).

Stated preference methods, such as contingent valuation, ask individuals how much they are willing to pay for a given good or service or how much they would be willing to accept as compensation for a given harm. These methods often assess non-use values; for example, what is the value of a protected wilderness for people who never see it?

Using previous estimates from other revealed or stated preference studies requires caution. These methods capture the value resulting from the complexity inherent in a specific study area. As such there is risk in applying these results to different contexts and subsequent benefit valuations.

Finally, avoided cost analysis examines the marginal cost of providing the equivalent service in another way. For example, rainfall retention and infiltration can offset a water utility's cost to capture, transport, treat and return each additional gallon of runoff. (Tomalty et al 2009; King and Mazzotta 2000).

Customized application of nonmarket valuation methods can be expensive and time consuming to perform. Contingent valuation, for example, can require conducting survey research; a hedonic pricing study may involve extensive data assembly.

There are many existing tools available to those interested in assessing the performance and value of green infrastructure practices, including online calculators, spreadsheet models and desktop software. These tools can be used as a companion to this guide and in many cases will be able to provide calculations with greater sensitivity to locally specific variables than those presented here. A full list and description of these tools can be found in Appendix A.

Our Framework

This guide outlines a framework for measuring and valuing green infrastructure's multiple ecological, economic and social benefits. The following sections integrate existing research on the benefits of five green infrastructure practices that are representative of the current vocabulary of GI in terms of applicable values and possible benefits. These sections explore how to:

- Measure the benefits from each particular practice
- Assign value to those benefits (in monetary terms when possible)

The guide follows a consistent sequence when analyzing each of the benefits defined in the previous section. This analysis allows users to evaluate the cumulative benefits of green infrastructure practices in a number of different benefit categories including water, energy, air quality and climate change. The following describes the two-step framework for this valuation process.

Step 1: Quantification of Benefits

It is first necessary to define a resource unit for the given benefit. For example, when evaluating energy benefits, the resource units are kilowatt hours (kWh) and British thermal units (Btu). Once the resource units are determined, the guide outlines the process for estimating the level of benefit for each practice. Step 1 concludes with an estimate of the total resource units received from a given benefit.

Step 2: Valuation of Quantified Benefits

In this step, values for each benefit are determined based on the resource units from the previous step. The method for translating resource units into a dollar figure differs for every benefit category. For example, the average cost of a kilowatt hour of electricity provides the direct cost saving value of reduced energy use. Because these values are extremely location and site specific, it is beyond the scope of this guide to demonstrate all parameters and local values. Examples demonstrated in this section illustrate the process necessary for determining the accrued value of green infrastructure implementation. Resources and guidance are provided where possible to help tailor these estimates to local projects, however much of the localized information must be gathered by the user. Please note, given the current state of valuation research, this step has not been addressed in the following benefit sections:

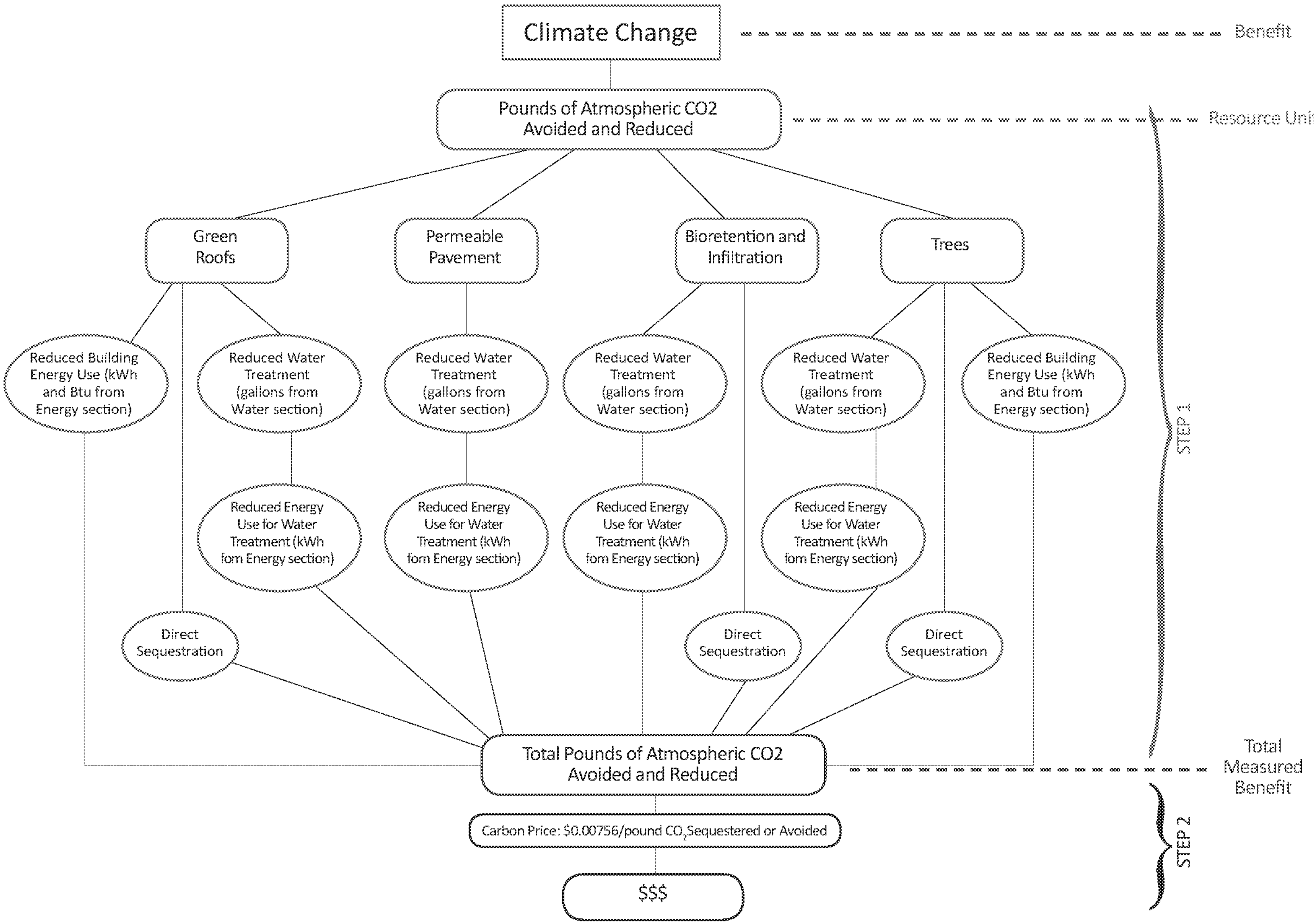
- Urban Heat Island
- Community Livability
- Habitat
- Public Education

Even if no monetary value can be assigned, these services provide valuable benefits which are still worth recognizing in a broader assessment of infrastructure investments.

It is important to keep in mind that the methods described here face a number of limitations. Although the discussion will focus on benefits, estimating the net value of a project would require a comparison of the net benefits compared to the lifecycle cost of constructing and maintaining a given green infrastructure practice. While life cycle cost analysis is beyond the scope of this guide, the Green Values™ Calculator (CNT 2009) can describe the relative cost of the green infrastructure practices (using cost data information through 2009).

Finally, several benefits face uncertainties about both spatial and temporal scale. The "Considerations and Limitations" section at the end this guide further addresses these and other concerns.

The figure below is an illustrative example of the process for valuing the Climate Change benefit section of green infrastructure.



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Benefit Measurement and Valuation

1. WATER

STEP 1 - QUANTIFICATION OF BENEFIT: REDUCED STORMWATER RUNOFF

The first step in valuing the water benefits from green infrastructure is to determine the volume of rainfall (in gallons) retained on site; this volume becomes the resource unit for all water benefits. When working through the calculations, keep in mind that some of the ranges given are based on the compilation of multiple cases studies and there may be more site-specific numbers to plug into the given equations. Where possible, the guide will suggest strategies for determining site-specific information.

Practices that provide water benefits include green roofs, permeable pavement, bioretention and infiltration, trees and water harvesting.

GREEN ROOFS

To quantify the stormwater runoff retained from green roofs, it is necessary to know the following information:

- Average annual precipitation data (in inches) for the site
- Square footage of the green infrastructure feature
- Percentage of precipitation that the feature can retain

The highly site-specific variables influencing the percentage of annual rainfall that a green roof is capable of retaining, listed below, are important considerations:

- The most important variable influencing the runoff reduction performance of the green roof is the depth of the growing media. The deeper the roof, the more water retained in the media.
- The growing media's antecedent moisture content will influence stormwater retention for any given storm event. This means that irrigation practices and storm frequency affect overall performance.
- Local climate variables also influence stormwater retention performance. For example, hotter, less humid climates lead to less antecedent moisture and more stormwater retention capacity.
- All else being equal, flat roofs retain more stormwater than sloped roofs.
- Size and distribution of storm events affect total stormwater retention. For example, holding the retention rate and annual precipitation constant, a green roof in a place with many small storms retains a greater percentage of the total rainfall than a green roof in a place with fewer, larger storms.

The following equation relies on two conversion factors. The 144 sq inches/square foot (SF) will convert the precipitation over a given area into cubic inches. Then, the factor of 0.00433 gal/cubic inch (i.e. the number of gallons per cubic inch) will convert that volume of precipitation into gallons, which is needed to quantify the amount of runoff reduced.

[annual precipitation (inches) * GI area (SF) * % retained] * 144 sq inches/SF * 0.00433 gal/cubic inch = total runoff reduction (gal)

Empirical studies of green roof stormwater retention performance have found that green roofs can retain anywhere from 40 to 80 percent of annual precipitation. The calculation in Example 1.1

uses the average of this range, or a 60 percent retention rate, to demonstrate a mid-range performance number:

Example 1.1:
A green roof with an area of 5,000 SF, using a 60% retention rate, will reduce annual runoff in Chicago, Ill. as follows:

*[38.01 inches annual precipitation * 5,000 SF area * 0.60 retention rate] * 144 sq inches/SF * 0.00433 gal/cubic inch = 71,100 gallons of runoff reduced annually*

TREE PLANTING

Water interception estimates, determined on a per tree basis, are needed to calculate the amount of stormwater runoff reduced from a given project. Therefore, it is necessary to know the number of trees being planted and their size and type. For example, the larger leaf surface area on one kind of tree will intercept more rainfall than will a smaller tree or leaf. In addition, the rate at which trees intercept rainfall is significantly impacted by a site's climate zone, precipitation levels and seasonal variability, which affects evapotranspiration rates.

The Center for Urban Forest Research of the US Forest Services, utilizing its STRATUM model, has compiled a set of *Tree Guides* that take into account many of these factors and estimate the level of benefits provided by trees:
http://www.fs.fed.us/psw/programs/cufr/tree_guides.php

These guides are organized by STRATUM climate zone which can be determined from the map provided at:
http://www.fs.fed.us/psw/programs/cufr/images/ncz_map.jpg

Table 1.1
Annual Rainfall Interception in Gallons from 1 tree, 40-year average, Midwest Region

	Small tree: Crabapple (22 ft tall, 21 ft spread)	**Medium tree: Red Oak** (40 ft tall, 27 ft spread)	**Large tree: Hackberry** (47 ft tall, 37 ft spread)
Rainfall Interception	292 gallons	1,129 gallons	2,162 gallons

Source: McPherson, E. et al. (2006).

Once the climate zone is determined, the tables in the tree guides' appendices are structured according to size of tree, with an example tree type provided. Average annual volume of rainfall interception can then be estimated based on these factors on a per tree basis. Table 1.1 provides an example of this information.

Using these values, the following equation provides an estimate for the volume of runoff intercepted on site:

**number of trees *
average annual interception per tree (gal/tree)
= total runoff reduction (gal)**

Example 1.2:
This example demonstrates the annual reduction in runoff yielded from planting 100 medium red oaks in the Midwest Region.

*100 medium trees * 1,129 gal/tree = 112,900 gallons of runoff reduced annually*

BIORETENTION AND INFILTRATION

Well-designed bioretention and infiltration features capture all or nearly all of the precipitation which falls on the feature and its related drainage area. However, in an urban context, the percentage of rainfall that these features can accommodate depends on available square footage and locally determined maximum ponding times. Determining a more site-specific performance measure requires complex hydrological modeling. The equation for determining the capacity of a bioretention feature requires the following information:

- Area and depth of the bioretention feature
- Relevant drainage area contributing runoff to the infiltration area
- Average annual precipitation data (in inches)
- Expected percentage of retention

These variables also affect the feature's retention percentage:

- Rainfall amount and distribution
- Site irrigation practices
- Temperatures and humidity
- Soil infiltration rate (based on soil type)

The following equation provides a simplified estimate of the potential volume of runoff captured using bioretention and infiltration practices:

[annual precipitation (inches) * (feature area (SF) + drainage area (SF)] * % of rainfall captured] * 144 sq inches/SF * 0.00433 gal/cubic inch = total runoff reduction (gal)

Example 1.3:

A site in Chicago, Ill. that retains 80% of stormwater runoff, with an infiltration area of 2,000 square feet and a drainage area of 4,000 square feet, reduces the volume of runoff as follows:

*[38.01 inches annual precipitation * (2,000 SF + 4,000 SF) * 0.80 retention rate] * 144 sq inches/SF * 0.00433 gallons/cubic inch = 113,760 gallons of runoff reduced annually*

PERMEABLE PAVEMENT

To quantify the water retained from permeable pavement, it is necessary to know the following information:

- Average annual precipitation data (in inches) for the site
- Square footage of the green infrastructure feature
- Percentage of precipitation that the feature is capable of retaining

Depending on the intensity of the precipitation event, studies have shown that pervious pavement can infiltrate as much as 80 to 100% of the rain that falls on a site (Booth et al 1996; Bean et al 2005; MMSD 2007; USEPA and LID Center 2000). Example 1.2 uses the lower end of this range, or an 80% retention rate. To find a more site-specific percentage, the following factors must be considered:

- Slope of the pavement – flat surfaces typically infiltrate more water
- Soil content & aggregate depth below pavement
- Size and distribution of storm events
- Infiltration rate
- Frequency of surface cleaning

The following equation quantifies the total amount of runoff that a given permeable pavement installation can reduce annually. As with the bioretention and infiltration calculations, the percentage of rainfall that these features can accommodate depends on available square footage and locally determined maximum ponding times:

[annual precipitation (inches) * GI area (SF) * % retained] * 144 sq inches/SF * 0.00433 gal/cubic inch = total runoff reduction (gal)

Example 1.4:
A permeable pavement feature with an area of 5,000 SF, using an 80% retention rate, will reduce annual runoff in Chicago, Ill. as follows:

*[38.01 inches annual precipitation * 5,000 SF area * 0.80 retention rate] * 144 sq inches/SF * 0.00433 gal/cubic inch = 94,800 gallons of runoff reduced annually*

WATER HARVESTING

Benefits from water harvesting are based on the volume in gallons of stormwater runoff stored onsite. To determine this volume, the following information is necessary:

- Average annual precipitation data (in inches)
- Rainfall intensity
- Size of the water-collecting surface (in square feet)
- Capacity for temporary water storage and release
- Frequency of harvested water use for building needs, irrigation or evaporative cooling (e.g. whether the captured rainwater is used before a subsequent rain event)

For every square foot of roof collection area, it is possible to collect up to 0.62 gallons of runoff per inch of rain with perfect efficiency. However, an efficiency factor of 0.75–0.9 is included in the equation to account for water loss due to evaporation, inefficient gutter systems and other factors (Texas Water Development Board 2005).

Applying the following formula provides a basic understanding of how much rainwater could be captured by this practice, both for site specific measurement as well as a cumulative calculation across a community or region.

annual rainfall (inches) * area of surface (SF) * 144 sq inches/SF * 0.00433 gal/cubic inch * 0.85 collection efficiency = water available for harvest (gal)

Example 1.5:
The following equation illustrates how to determine the capacity of a water harvesting practice using annual rainfall data for Chicago, Ill.:

*38.01 inches annual rainfall * 1,000 SF of surface * 144 sq inches/SF * 0.00433 gal/cubic inch * 0.85 collection efficiency = 20,145 gallons captured annually*

After estimating the gallons of stormwater a particular site and practice can retain (i.e. the total resource units), this information should be used in Step 2.

STEP 2 - VALUATION OF QUANTIFIED BENEFITS: REDUCED STORMWATER RUNOFF

The valuation process in the "Water" section is divided into the following four subsections and outlines each separately:

- Reduced Water Treatment Needs
- Reduced Grey Infrastructure Needs
- Improved Water Quality
- Reduced Flooding

Methods for valuation will only be provided in the "Reduced Water Treatment Needs" and "Reduced Grey Infrastructure Needs" subsections. The other two sections discuss benefits and current research, but they do not present a formal valuation method, given the amount of varying factors required to value these benefits.

Reduced Water Treatment Needs

For cities with combined sewer systems (CSS), stormwater runoff entering the system combines with wastewater and flows to a facility for treatment. One approach to value the reduction in stormwater runoff for these cities is an avoided cost approach. Runoff reduction is at least as valuable as the amount that would be spent by the local stormwater utility to treat that runoff. In this case, the valuation equation is simply:

runoff reduced (gal) * avoided cost per gallon ($/gal) = avoided stormwater treatment costs ($)

Example 1.6:
The Metropolitan Water Reclamation District of Greater Chicago has a marginal cost of treating its wastewater and stormwater of $0.0000919 per gallon (CNT 2009). Using Example 1.1, in which the 5,000 SF green roof provided a runoff reduction of 71,100 gallons, the annual avoided cost for water treatment associated with this site becomes:

*71,100 gallons * $0.0000919/gallon = $6.53 in annual avoided treatment costs*

Keep in mind, the figure from this example is a single unit that can be aggregated to a larger scale, demonstrating the cumulative benefit that can be achieved within a neighborhood or region. Additionally, avoided cost approaches inevitably underestimate the full value of an ecosystem service. As such, this figure should be considered a lower bound for the monetary value of reduced stormwater runoff. More locally specific treatment costs are available from local water treatment utilities.

Reduced Grey Infrastructure Needs

Green infrastructure practices can reduce the volume of water needing treatment as well as the level of treatment necessary. Therefore, utilizing these practices can reduce the need for traditional or grey infrastructure controls for stormwater and combined sewer overflow (CSO) conveyance and treatment systems, including piping, storage and treatment devices. Similar to the approach taken in other sections of this guide, the value of reducing grey infrastructure derives from the benefits transfer method of avoided costs resulting from the use of green infrastructure. While the case studies below give examples of how these costs can be compared, it is beyond the scope of this guide to determine exact cost savings. This is due to the many site-specific variables that effect the monetary values involved, such as soil types, rainfall distribution patterns, peak flow rates and local materials costs.

One method of assessing avoided grey infrastructure costs when using green infrastructure practices is demonstrated by a case study in Portland, Oregon. In this study, the Bureau of Environmental Services estimated that it costs the city $2.71/SF in infrastructure costs to manage the stormwater generated from impervious areas (Evans 2008). The city uses the following equations to estimate the resulting avoided cost savings:

conventional cost of structure ($/SF) * total area of structure (SF) = total expenditure for conventional approach ($)

total expenditure for conventional approach ($) * % retained = avoided cost savings ($)

Please note, while the typical resource unit used within this "Water" section is *gallons* of stormwater retained, this particular benefit instead considers *percent* of stormwater retained.

Example 1.7:

Using Portland, Ore. as an example, a 5,000 SF conventional roof would have a one-time expenditure of $13,550. However, by utilizing a green roof, which in this particular study has been shown to retain 56 percent of runoff, Portland can expect an avoided cost savings of $7,588:

*$2.71/SF * 5,000SF = $13,550 in total conventional expenditure*

*$13,550 * 56% = $7,588 avoided cost savings*

Groundwater Recharge

Green infrastructure practices that enable rainwater infiltration contribute to the recharge of both deep aquifers and subsurface groundwater. When rain falls on a permeable surface, some runs off, some returns to the atmosphere through evapotranspiration and the remainder is infiltrated into the ground. This infiltrated water either recharges aquifers or joins subsurface flows, which end up in local streams. Both aquifer recharge and subsurface flow are important components of a functional water cycle that sustains the ecosystem services on which human activity depends.

Aquifers provide water for drinking and irrigation. Aquifer levels are essentially a function of the relationship between discharge (withdrawal by humans, evaporation, interaction with surface waters) and recharge (primarily infiltrated precipitation). Over time, withdrawing more from an aquifer than is recharged through precipitation can cause declining aquifer levels, resulting in higher pumping costs, reduced water availability and even land subsidence that can result in sink holes.

Green infrastructure affects groundwater recharge in highly site-specific ways. Some infiltrated rainfall may discharge back into surface waters after a few days; in other cases, generations may pass before infiltrated water again becomes available for human use. For this reason, this work does not define specific guidelines for quantifying and valuing the groundwater recharge benefit of green infrastructure. Nonetheless, it is important for the future health of watersheds to monitor aquifer levels and stream flows and consider the benefits of restoring infiltration.

Another study, in the Blackberry Creek watershed near Chicago, Illinois, estimated the benefits attributable to green infrastructure practices resulting from avoided costs of infrastructure that would have been needed to control reduced peak discharges (Johnston, Braden and Price 2006). The study found that, based on Federal Highway Department pipe sizing requirements, reduced peak discharges within their low impact development scenario resulted in a downstream benefit of $340 per developed acre. This is an initial cost savings; performing a life-cycle cost analysis would better demonstrate long-term monetary benefits. The calculations for this method are dependent on access to the following variables and results are best determined through the use of hydrologic modeling:

- Peak flow rates
- Allowable ponding time
- Pipe size requirements

In the case of Seattle's Street Edge Alternatives (SEA) project, which utilizes bioswales to capture and treat stormwater runoff, Seattle Public Utilities found that bioretention combined with narrowing the roadway, eliminating the traditional curb and gutter, and placing sidewalks on only one side of the street garners a cost savings for the city of 15–25 percent, or $100,000–$235,000 per block, as compared to conventional stormwater control design (SPU). Additionally, Seattle Public Utilities has identified cost savings in terms of the life span of the project; SEA streets are designed to improve performance as plantings mature, whereas traditional systems tend to degrade over time (Wong and Stewart 2008).

Improved Water Quality

Using green infrastructure for stormwater management can improve the health of local waterways by reducing erosion and sedimentation and reducing the pollutant concentrations in rivers, lakes and streams. These effects, in turn, lead to improved overall riparian health and aesthetics—indicators of improved water quality and channel stabilization.

The impacts of green infrastructure on water quality, while well documented, are too place-specific to provide general guidelines for measurement and valuation. The water quality improvements associated with green infrastructure, furthermore, are not of sufficient magnitude to be meaningful at the site scale. This benefit, therefore, is best evaluated in the context of watershed-scale green infrastructure implementation, accompanied by hydrologic modeling, to estimate changes in sedimentation and pollutant loads resulting from a green infrastructure program.

Regulators measure water quality in a variety of ways. Damaging pollutants carried by stormwater runoff typically include nitrogen, phosphorous and particulate matter. Water quality monitors can measure concentrations of dissolved nitrogen and phosphorous, as well as total suspended solids (TSS), usually in milligrams per liter. In economic valuations, water *clarity* is often used as a proxy measure for water *quality*. While only an approximate measure, water clarity strongly correlates with the presence of phosphorous, nitrogen and TSS pollution. Suspended particulates directly decrease water clarity, while high concentrations of nitrogen and phosphorous lead to eutrophication—a process whereby increased nutrients in waterways lead to algae blooms which cloud the water and decrease dissolved oxygen. In extreme cases, eutrophication can lead to hypoxic conditions, characterized by the absence of sufficient oxygen to support any animal life. Water clarity is typically measured using the Secchi disk test, in which a black and white patterned disk is lowered into the water until no longer visible; this depth is considered the water clarity depth.

Previous research has applied a benefits transfer approach to quantify the expected improvement in water clarity resulting from a green infrastructure program. Several hedonic pricing studies estimated the impact of water clarity changes on lakefront property values. Studies in Maine and New Hampshire have estimated implicit marginal prices for a one meter change in water clarity ranging from $1,100 to $12,938 per lakefront property (Gibbs et al 2002; Boyle et al 1999; Michael et al 1996). A hedonic pricing study of the St. Mary's River Watershed in the Chesapeake Bay estimated home price impacts of water quality changes not merely for waterfront properties but for the entire watershed. It found marginal implicit prices for changes of one milligram per liter in total suspended solids (TSS) concentration of $1,086 and in dissolved inorganic nitrogen (DIN) concentration of $17,642 for each home in the watershed (Poor et al 2007).

Reduced Flooding

By reducing the volume of stormwater runoff, green infrastructure can reduce the frequency and severity of flooding. The impact of green infrastructure on flooding is highly site and watershed specific, and thus this guide does not provide general instructions for quantifying the reduction in flood risk resulting from a green infrastructure program.

There are several ways to assess the value of reduced flood risk provided by green infrastructure practices on a watershed-scale once the risk impacts have been modeled. Some studies use hedonic pricing to examine how flood risk is priced into real estate markets; others use the insurance premiums paid for flood damage insurance as a proxy for the value of reducing the risk of flood damage; others take an avoided damage cost approach and still others have employed contingent valuation methods.
The most robust literature on the economic valuation of flood risk uses hedonic pricing methods to investigate the housing price discount associated with floodplain location. Most of these studies estimate the impact on residential home prices of locations inside or outside of the 100-year floodplain. Those considering implementing a green infrastructure program who are able to model resulting changes in floodplain maps—in particular, to identify the area where annual flood risk is greater than one percent and can be reduced to less than one percent through the use of green infrastructure—can apply the results of these studies to get an estimate of the range of value provided by green infrastructure's flood risk reduction impact.

Until recently, hedonic price studies have found that homes within the 100-year floodplain are discounted between two and five percent compared with equivalent homes outside the floodplain (Braden and Johnston 2004; Bin and Polasky 2004; MacDonald et al 1990; Harrison, Smersh and Schwartz 2001; Shilling, Benjamin and Sermins 1985; MacDonald, Murdoch and White 1987).

In recent years, hedonic pricing techniques have evolved to recognize that hazard risk may be correlated with spatial amenities or disamenities. In the case of flooding, a correlation exists between proximity to waterways and flood risk. Studies that fail to disentangle this correlation will likely underestimate the amount that flood-prone properties are discounted in the marketplace and thus underestimate the value of flood risk

Reduced Salt Use

Research indicates that using pervious pavement can reduce the need for road salt use by as much as 75 percent (Houle 2006). Reducing salt use saves money for individual property owners and municipalities while also protecting water supplies and the environment as a whole. The following variables affect the performance of permeable pavement in reducing salt use:

- Infiltration rate
- Frequency of surface cleaning
- Soil content and aggregate depth below pavement

A study in Iowa comparing the temperature behavior of traditional concrete and Portland Cement Pervious Concrete (PCPC) found the following: "The results show that the aggregate base underneath the pervious concrete substantially delayed the formation of a frost layer and permeability was restored when melt water is present. . . . The melt water immediately infiltrated the pervious concrete pavement, eliminating the potential for refreezing and reducing the slip/fall hazard associated with impervious surfaces" (Kevern et al 2009b).

The National Research Council (NRC) indicates that road-salt use in the United States ranges from 8 million to 12 million tons per year with an average cost of about $30 per ton (Wegner and Yaggi 2001), although this cost has increased in recent years. In winter 2008, many municipalities paid over $150 per ton for road salt; projections for 2009 reported salt prices in the range of $50–$70 per ton (Associated Press 2009; Singer 2009).

reduction. One study applied these new techniques to account for the correlation of flood risk and coastal amenities and found that homes in the 100-year floodplain were discounted an average of 7.8 percent compared to equivalent homes outside the floodplain (Bin, Kruse and Landry 2008). Therefore, we recommend that users of this guide apply the 2–5 percent range as a conservative estimate of the value of flood risk reduction.

US Census Summary File 3[1] provides median home price data and the number of owner-occupied housing units at the block group level.

An example application of this method can be found in a study on green infrastructure implementation in Blackberry Creek Watershed in Kane County, Illinois (Johnston, Braden and Price 2006). The authors used the USEPA's *Hydrologic Simulation Program—Fortan* to model the difference in peak flows of a green infrastructure versus a conventional development scenario. They then input their peak flow results into the Army Corps of Engineers' Hydrologic Engineering Center River Analysis System and found that conventional development would add 50 acres to the floodplain compared to development using green infrastructure for stormwater management. Applying an anticipated density of 2.2 units/acre and the census bureau's reported median home value of $175,600, the study then used the benefits transfer approach to estimate a range of values for flood risk reduction. Using a range of 2–5 percent property value increase for removal from the floodplain yields total benefits of between $391,600 and $979,000 for the flood risk reduction impact of the green infrastructure scenario.

[1] US Census Bureau. American Factfinder: http://factfinder.census.gov/home/saff/main.html?_lang=en

Benefit Measurement and Valuation

2. ENERGY

STEP 1 - QUANTIFICATION OF BENEFIT: REDUCED ENERGY USE

The first step to valuing the benefits of reduced energy use is determining the amount of energy saved by each practice. This section quantifies the benefit of energy savings in terms of kilowatt hours (kWh) of electricity and British thermal units (Btu) of natural gas reduced.

Practices that reduce building energy use include green roofs and trees. In addition, green infrastructure can reduce off-site energy use by preventing runoff and by reducing the demand for potable water. Both of these benefits lead to a decrease in water treatment needs, thereby lowering energy use at treatment facilities. Because facility energy costs are incorporated into the cost of treatment, direct energy cost savings have already been captured. Thus, this section will not value the energy benefit from reduced water treatment, as this would result in double counting.

However, benefits from reduced treatment-plant energy use go above and beyond direct cost savings. This guide will provide methods for estimating the indirect benefits of reduced energy use from both air quality improvements and reduced climate change impacts. Therefore, refer to the "Air Quality" and "Climate Change" sections to quantify these.

GREEN ROOFS

When considering to what degree green roofs reduce building energy use, it is important to keep in mind that heat flux through the roof is only one of many factors influencing building energy consumption. A dramatic improvement in energy performance from green roofs compared to conventional roofs may have only a small impact on overall building energy use. That said, to provide a simple estimate of building energy savings, the suggested method treats green roofs as insulation and assumes that a reduction in heat flux translates directly into energy savings (Clark, Adriaens, and Talbot 2008). Equations for both cooling and heating savings can be derived as follows:

annual number of cooling degree days (°F days) * 24 hrs/day * ΔU = annual cooling savings (Btu/SF)

annual number of heating degree days (°F days) * 24 hrs/day * ΔU = annual heating savings (Btu/SF)

Where:
U = heat transfer coefficient, or 1/R; and
R = a measure of thermal resistance.

Therefore, the main pieces of information necessary for this calculation are the average degree days (both cooling and heating) and the ΔU, which will be calculated from R-values (for both the green roof and a conventional roof with which to compare it).

Determining Cooling and Heating Degree Days (°F days)

The EPA defines Cooling and Heating Degree Days as follows:

"*Cooling degree days* are used to estimate how hot the climate is and how much energy may be needed to keep buildings cool. CDDs are calculated by subtracting a balance temperature from the mean daily temperature, and summing only positive values over an entire year. The balance temperature used can vary, but is usually set at 65°F (18°C), 68°F (20°C), or 70°F (21°F).

Heating degree days are used to estimate how cold the climate is and how much energy may be needed to keep buildings warm. HDDs are calculated by subtracting the mean daily temperature from a balance temperature, and summing only positive values over an entire year. The balance temperature used can vary, but is usually set at 65°F (18°C), 68°F (20°C), or 70°F (21°F)."
http://www.epa.gov/hiri/resources/glossary.htm

To assign values for cooling and heating degree days, this guide recommends using the cooling and heating degree day "Normals" from the National Climatic Data Center of the National Oceanic and Atmospheric Administration.
http://lwf.ncdc.noaa.gov/oa/documentlibrary/hcs/hcs.html

Determining R-Values and ΔU

According the USEPA, "*R-value* or 'thermal resistance value' is a measure of the resistance of a material to heat flow. The term is typically used to describe the resistance properties of insulation. The higher the R-value, the greater the insulation's resistance to heat flow."
http://www.epa.gov/hiri/resources/glossary.htm

R-values are reported in the units of square feet * degrees Fahrenheit * hours per British thermal unit (SF * °F * hrs/Btu).

The U-value, or the overall heat transfer coefficient, is defined as the inverse of R. Therefore, to find the ΔU, R-Values for the given conventional and green roof are necessary. Clark, Adriaens and Talbot (2008) provide a valuable explanation for estimating R-values for conventional roofs as well as green roofs based on media depth (p. 2,156). For illustrative purposes, the subsequent example uses default values as follows:

For conventional roofs: **R = 11.34 SF * °F * hrs/Btu**
For green roofs: **R = 23.4 SF * °F * hrs/Btu**
(Clark, Adriaens, and Talbot 2008)

The ΔU can be calculated as follows:

$$\Delta U = \left(\frac{1}{R_{\text{conventional roof}}}\right) - \left(\frac{1}{R_{\text{green roof}}}\right) \quad \text{or} \quad \Delta U = \left(\frac{\text{Btu}}{11.34{*}\text{SF}{*}°\text{F}{*}\text{hrs}}\right) - \left(\frac{\text{Btu}}{23.4{*}\text{SF}{*}°\text{F}{*}\text{hrs}}\right)$$

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Example 2.1:
In this example, the annual cooling savings (kWh) of a 5,000 SF green roof in Chicago, Ill. is calculated as follows:

At Station 32: Illinois Chicago Botanical Garden, the 1971–2000 Normals for Annual Cooling Degree Days is 702 °F days.

annual number of cooling degree days (°F days) * 24 hrs/day * ΔU = annual cooling savings (Btu/SF)

$$702°\text{Fdays} \times \frac{24\text{hrs}}{\text{day}} \times \left[\left(\frac{\text{Btu}}{11.34{*}\text{SF}{*}°\text{F}{*}\text{hrs}}\right)\right] - \left[\left(\frac{\text{Btu}}{23.4{*}\text{SF}{*}°\text{F}{*}\text{hrs}}\right)\right] = \textit{annual cooling savings}$$

$$16{,}848°\text{F} * \text{hrs} \times \left[\left(\frac{\text{Btu}}{11.34{*}\text{SF}{*}°\text{F}{*}\text{hrs}}\right)\right] - \left[\left(\frac{\text{Btu}}{23.4{*}\text{SF}{*}°\text{F}{*}\text{hrs}}\right)\right] = \textit{annual cooling savings}$$

$$\frac{16{,}848\ \text{Btu}}{11.34\ \text{SF}} - \frac{16{,}848\text{Btu}}{23.4\ \text{SF}} = \textit{annual cooling savings}$$

$$\frac{1{,}485.71\ \text{Btu}}{\text{SF}} - \frac{720\ \text{Btu}}{\text{SF}} = \textit{annual cooling savings}$$

$$765.71\ \text{Btu/SF} = \textit{annual cooling savings}$$

In order to find how cooling savings results in electricity savings (kWh), the Btu units should be converted to kWh using the conversion rate of 1 kWh/3412 Btu. By converting Btu to kWh, annual cooling savings becomes:

$$\frac{765.71\ \text{Btu}}{\text{SF}} \times \frac{1\ \text{kWh}}{3{,}412\ \text{Btu}} = 0.2244\text{kWh/SF} = \textit{annual cooling savings}$$

Thus, for the 5,000 SF green roof, annual electricity cooling savings is: **5,000 SF * 0.2244 kWh /SF = 1,122 kWh**

Example 2.2:
In this example, the annual heating savings (Btu) of a 5,000 SF green roof in Chicago, Ill. is calculated as follows:

At Station 32: Illinois Chicago Botanical Garden, the 1971–2000 Normals for Annual Heating Degree Days is 6,630 °F days.

annual number of heating degree days (°F days) * 24 hrs/day * ΔU = annual heating savings (Btu/SF)

$$6{,}630^\circ F days \times \frac{24 hrs}{day} \times \left[\left(\frac{Btu}{11.34*SF*^\circ F*hrs}\right)\right] - \left[\left(\frac{Btu}{23.4*SF*^\circ F*hrs}\right)\right] = \textit{annual heating savings}$$

$$159{,}120^\circ F * hrs \times \left[\left(\frac{Btu}{11.34*SF*^\circ F*hrs}\right)\right] - \left[\left(\frac{Btu}{23.4*SF*^\circ F*hrs}\right)\right] = \textit{annual heating savings}$$

$$\frac{159{,}120 Btu}{11.34 SF} - \frac{159{,}120Btu}{23.4 SF} = \textit{annual heating savings}$$

$$\frac{14{,}031.75 Btu}{SF} - \frac{6{,}800 Btu}{SF} = \textit{annual heating savings}$$

$$7{,}231.75 Btu/SF = \textit{annual heating savings}$$

Since the assumption here is that heating is provided by natural gas, the annual heating natural gas (Btu) savings for the 5,000 SF green roof is:

5,000 SF * 7,231.75 Btu/SF = 36,158,750 Btu

The actual benefits realized in terms of energy savings due to the implementation of a green roof will be significantly impacted by the following variables:

- Growing media composition, depth and moisture content
- Plant coverage and type
- Building characteristics, energy loads and use schedules
- Local climate variables and rainfall distribution patterns

TREE PLANTING

Many variables affect the ability of trees to reduce energy use in neighboring buildings. Perhaps the largest determinant is climate zone. Shading buildings in cool regions can actually increase energy demand, while reducing wind speeds in warm regions will have little to no impact. As the two following examples show, the location of tree plantings relative to buildings also plays a critical role in determining the level of benefits. Climate zone and building aspect must be considered in conjunction to realize the greatest building energy reduction benefits. The size, and therefore age, as well as the type of tree also significantly impacts the level to which trees evapotranspire, provide shade and act as windbreaks.

The Center for Urban Forest Research of the US Forest Service using its STRATUM model, compiled a set of *Tree Guides* that take into account many of these factors and estimate the level of benefits provided by trees:
http://www.fs.fed.us/psw/programs/cufr/tree_guides.php

These guides are organized by STRATUM climate zone which can be determined from the map provided at:
http://www.fs.fed.us/psw/programs/cufr/images/ncz_map.jpg

Once the climate zone is determined, the tables in the tree guides' appendices are structured according to size of tree (with an example tree type provided) as well as the location of the tree with respect to buildings. Average reductions in building energy use can then be estimated based on these factors on a per tree basis.

As an example, Tables 2.1 and 2.2 show the 40-year average electricity and natural gas savings from trees in the Midwest Region.

Table 2.1: 40-year Average Electricity Savings from Trees in the Midwest Region

	Residential Yard Opposite West-Facing Wall	Residential Yard Opposite South-Facing Wall	Residential Yard Opposite East-Facing Wall	Public Tree on a Street or in a Park
Small tree: Crabapple (22 ft tall, 21 ft spread)	96 kWh	54 kWh	68 kWh	48 kWh
Medium tree: Red Oak (40 ft tall, 27 ft spread)	191 kWh	99 kWh	131 kWh	67 kWh
Large tree: Hackberry (47 ft tall, 37 ft spread)	268 kWh	189 kWh	206 kWh	136 kWh

Source: McPherson, E. et al. 2006

Table 2.2: 40-year Average Natural Gas Savings from Trees in the Midwest Region

	Residential Yard Opposite West-Facing Wall	Residential Yard Opposite South-Facing Wall	Residential Yard Opposite East-Facing Wall	Public Tree on a Street or in a Park
Small tree: Crabapple (22 ft tall, 21 ft spread)	1,334 kBtu	519 kBtu	1,243 kBtu	1,534 kBtu
Medium tree: Red Oak (40 ft tall, 27 ft spread)	1,685 kBtu	-316 kBtu	1,587 kBtu	2,099 kBtu
Large tree: Hackberry (47 ft tall, 37 ft spread)	3,146 kBtu	2,119 kBtu	3,085 kBtu	3,430 kBtu

Source: McPherson, E. et al. 2006